Upper Republican 2D BLE

Alternative Approach Analysis

Kansas Department of Agriculture

Project reference: Upper Republican 2D BLE Hydrology Pilot Study

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Prepared for:

Kansas Department of Agriculture

Prepared by:

AECOM
2380 McGee Street
Kansas City, MO 64108
aecom.com

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1. Introduction

During the 2D Base Level Engineering (BLE) analysis of the Upper Republican 2D BLE custom watershed, AECOM noticed the discharge estimates derived from the regional regression equations differed significantly than those generated by a gage analysis at the same location. This discrepancy is likely due to groundwater irrigation causing flows in this area to decrease drastically over the years. AECOM's standard approach to validate the 2D models to both sources of discharge information is not reasonable for this custom watershed.

After performing hydrologic review, AECOM suggests discussion with KDA about an alternate approach for this area per FEMA Guidance (*General Hydrologic Considerations February 2019*). AECOM believes the regression equations overestimate flows in this watershed, and validating the 2D models to those estimates would not be representative and would overestimate the extent of the base flood. AECOM recommends using only the USGS stream gages with sufficient period of record as the source of validation for the 2D Base Level Engineering model data. This document provides the basis for this recommendation.

1.1 Study Region

The area chosen to conduct this study was in the Upper Republican River watershed. Two large scale 2D BLE models were developed along Beaver Creek, which encompassed two USGS Stream Gages (068640000 and 068465000). The area is mostly agricultural, with four communities; McDonald, Atwood, Ludell, and Herndon. Atwood being the largest community in the study area was focused on as an area of particular interest in calibration and comparison due to existing flood studies and maps in the community.

1.2 Historical Data

The two stream gages in the study area's in question, USGS 068460000 on Beaver Creek at Ludell, KS and USGS 06846500 Beaver Creek at Cedar Bluffs, KS, have extensive historical records. The highest flows recorded at the gage at Ludell, KS were in 1965 with 3,800 cfs flowing through that portion of the stream. This was accompanied by a gage height of 11.37 ft. The gage at Cedar Bluffs recorded slightly lower flows at this time, with 2,440 cfs, but a higher gage height of 16.69 ft. The highest recorded flow for the gage at Cedar Bluffs was in 1960, with a flow of 7,940 cfs and a gage height of 18.71 ft. This flooding event was most likely not captured by the gage at Ludell due to it not collecting data from 1954-1960.

2. Methodologies for 2D BLE

2.1 Standard 2D BLE Approach

When undertaking a large scale 2D BLE model, the standard methodologies include taking both historical gage data and Regression equations developed for each region by the USGS into consideration while verifying the peakflows within the model. Gage analyses are performed in accordance to Bulletin 17C procedures on streamflow gages within the study area with a sufficient period of record. The hydraulic models are compared to the gage estimates in these locations to verify the results are comparable to observed streamflow data. The gage data is the most reliable hydrologic information available for a gaged flooding source, so the gage comparison serves as the priority for model flow verification.

Due to the sparse availability of streamflow gages in a 2D BLE study area, additional streamflow comparison must be performed to verify model flows in ungaged basins and smaller drainage areas. USGS regression estimates are used to supplement the model flow verification and ensure the model flows are accurate throughout the watershed. Figure 1 displays the two regions determined by the USGS used for regression estimates in Kansas.

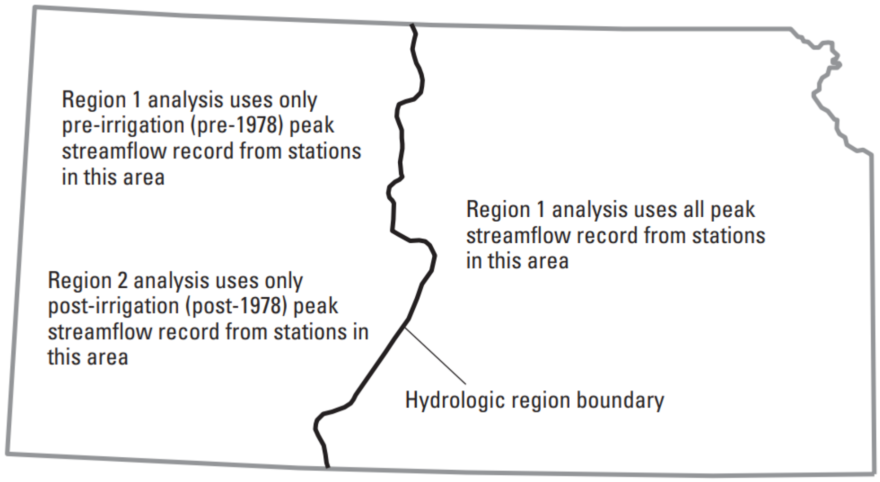

Figure 1: Hydrologic regions used in peak streamflow frequency analysis (Ref: https://pubs.usgs.gov/sir/2017/5063/sir20175063.pdf)

2.2 Regression vs. Gage Discharges

The impact of groundwater irrigation in Western Kansas is well-documented. The USGS Scientific Investigations Report 2017-5063, “Methods for Estimating Annual Exceedance-Probability Streamflows for Streams in Kansas Based on Data Through Water Year 2015” attempts to factor in the effects of irrigation on hydrology and peak flows, but compared to gage analyses, these regression estimates still overestimate flows. In the report, they have calculated a separate set of regression equations for the western half of Kansas (Region 2) that only use peak flows from gages after 1978. Peak streamflow data after 1978 was determined by the report as the period that reflects the condition of declining ground-water levels. Region 2 is shown as the area west of the irrigation-affected area boundary in Figure 3. The Region 2 equations were developed using 24 streamgages compared to 120 streamgages for Region 1. Of the 24 used in Region 2 regression calculations, only 3 exist in the Upper Republican watershed. Other gages in the area were discarded due to significant decreasing trends in peak streamflow. Figure 2 shows an example of peak streamflow record for USGS Gage 06821500. This gage in the Upper Republican watershed has experienced a severe decreasing trend in peak streamflow over the years. Less data causes the accuracy of the prediction to be lower. “The larger potential errors in western portions of the United States are attributed to greater at-site variability of the flood records, a sparser data network, and shorter periods of station record. All three of these factors are present to some degree in the irrigation-affected region of western Kansas and account for the extended upper range in the standard error of prediction.” (USGS 2017). AECOM believes the lack of gage data used to calculate the Region 2 regression estimates combined with the lack of influence of data from the Upper Republican watershed causes the regression equations to potentially misrepresent realistic flood discharges in the area.

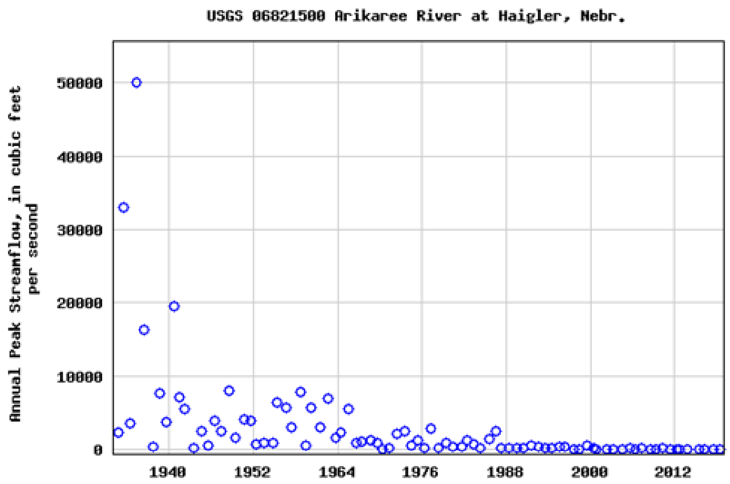

Figure 2: Peak Streamflow Record USGS Gage 06821500

Trends in streamflow have been attributed to groundwater irrigation, rather than a decrease in precipitation. AECOM will continue to use the NOAA precipitation estimates as a hydrologic input. “The lack of significant decreasing trends in precipitation in any of the study climate divisions and in any of the three tested periods along with the coincident distribution of highly irrigated land use, supports previous findings that the declines in peak streamflows likely are associated with documented changes in groundwater withdrawals for irrigation use” (USGS 2017). With many of the gages in the Upper Republican watershed being discarded from regression calculation, it is reasonable to assume that the lack of available data used to develop the equations may cause the estimates to misrepresent the low flows in the area.

Figure 3 shows the locations of gages with decreasing trends determined by SIR 2017-5063, many of which are near the Upper Republican watershed in northwestern Kansas. The issue of differing discharge data was not experienced by AECOM during the 2D BLE analyses of the Lower Arkansas and Verdigris watersheds due to more available gage data used to generate the regression equations and lack of groundwater withdrawal in those southeastern parts of the state.

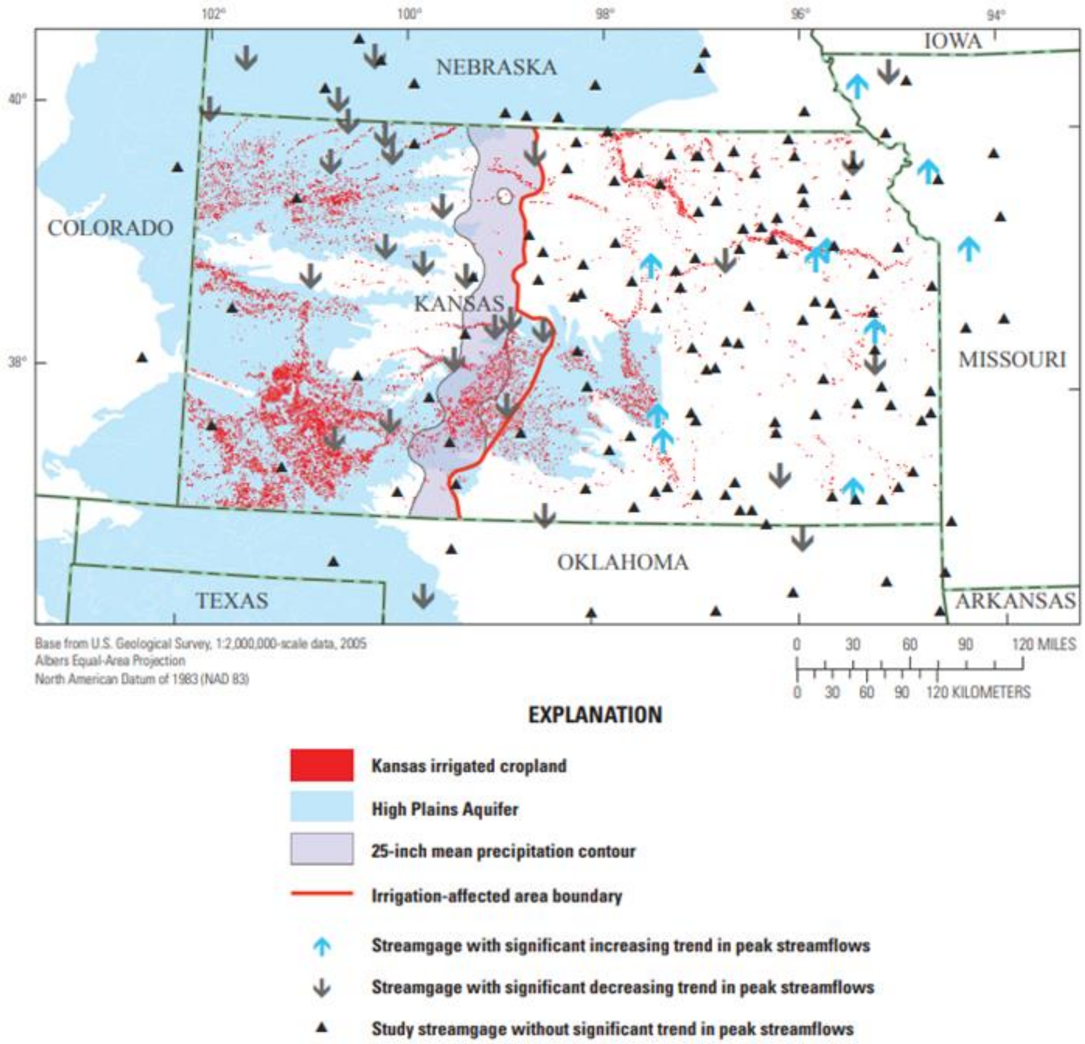

Figure 3: Trend Analysis of USGS Streamgages in SIR 2017-5063

The discharge discrepancy between the two choices for model validation can be highlighted by looking at the rural regression estimate (RRE) and the Bulletin 17C (EMA) gage analyses estimate for each gage site. Figure 4 shows the locations of the viable gages (20 years of record post-1978) within the Upper Republican Watershed. Table 1 shows a comparison of the regression and gage estimates at each location. From this analysis along with the information provided from SIR 2017-5063, AECOM concludes that the regression equations over predict the flood hazard in most cases for the Upper Republican Watershed when compared to gage analyses performed on gage records after 1978. The current approach using the Region 2 regression equations and the suggested gage analyses described in the USGS report SIR 2017-5063 neglects all flow prior to 1978. This eliminates many years of useful gage record that can provide greater accuracy and confidence in flood frequency estimates.

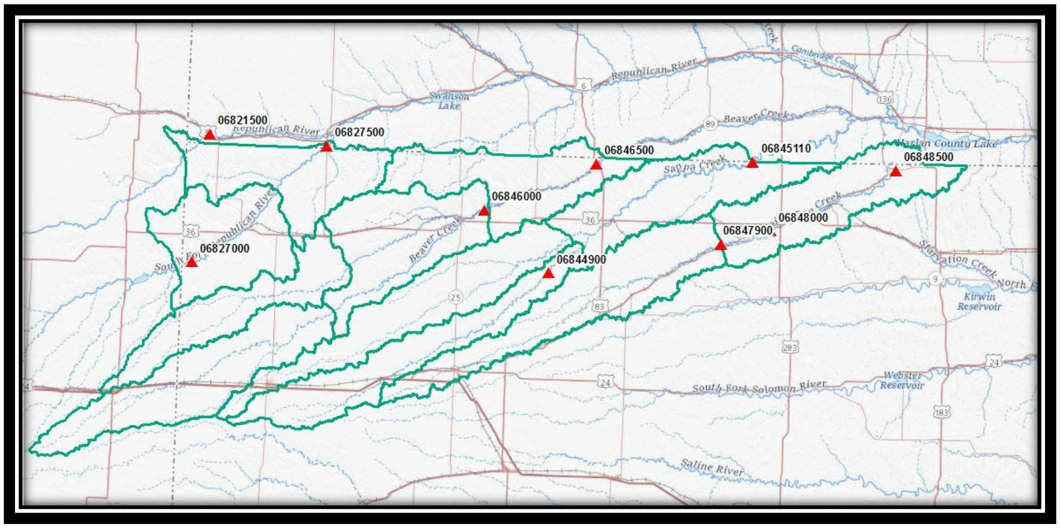

Figure 4: Gage locations within Upper Republican 2D BLE watershed

Gage ID	Location	Total Number of Peak Flows	Post-Irrigation Peak Flows	Drainage Area (mi^2)	Bulletin 17C Gage Analysis Estimate (cfs)	Rural Regression Estimate (cfs)	% Increase
06821500	Arikaree River at Haigler, NE	87	41	1,020	3,375	9,987	196%
06846500	Beaver Creek at Cedar Bluffs, KS	74	40	1,480	2,125	11,470	440%
06844900	SF Sappa Creek NR Achilles, KS	50	32	378	18,810	6,903	-63%
06847900	Prairie Dog Creek Above KS Lake	65	40	590	5,763	8,147	41%
06848000	Prairie Dog Creek at Norton, KS	59	25	684	113	8,607	7517%
06827000	SF Republican River NR CO-KS State Line	16	16	1,860	4,548	12,488	175%
06827500	SF Republican River NR Benkelman, NE	116	35	2,190	6,836	13,270	94%
06846000	Beaver Creek at Ludell, KS	52	33	1,117	1,829	10,330	465%
06845110	Sappa Creek Near Lyle, KS	22	22	1,488	1,951	11,493	489%
06848500	Prairie Dog Creek near Woodruff, KS	89	40	1,007	2,911	9,940	241%

Table 1: 1%-AEP Discharges at Gage Sites

2.3 Issues Using Current 2D BLE Approach

Typically, AECOM's 2D BLE approach is to validate the hydrologic outputs from the 2D models using the best available data for the area of interest. This is prioritized with USGS gage analyses as the first priority at the gage site, followed by regression estimates to validate flows throughout the rest of the watershed. This approach allows validation of the models along major flooding sources with larger drainage areas while also ensuring the modeled results in the upper portions of the watershed with smaller drainage areas align with best available data. However, the discharge discrepancy between regression equations and gage analyses makes this validation method unreasonable for the Upper Republican custom watershed.

The NRCS nested rainfall distribution was used in the hydrology models in order to validate to small and large drainage areas within the same model, but the distribution alone cannot account for the discharge discrepancy between regression and gages in the area. When trying to validate the models to regression equations in the upper portions of the watershed, as well as the gage discharge estimates in downstream parts of the watershed, the discharge in the 2D model becomes much higher than the weighted gage estimates. During model iterations, to validate the base flood in the 2D BLE, AECOM engineers have used typical hydraulic validation methods such as curve number and Manning's n roughness value adjustments, but results still significantly overestimate compared to 1978-present gage analyses. Figure 5 shows an example of the regression comparison and gage discharge comparison of one model in the area with USGS gage 06847900 near the downstream outlet. After several iterations of trying hydrologic and hydraulic edits to lower the flow at the outlet while maintaining high enough flows in the upper portions of the model, the model still shows discharges being near or lower than the 1-standard error of prediction for the regression equations and above the 1-standard error of prediction for the gage analysis. This shows the difficulty of using both sources of information for validation. As the models work further downstream and the drainage areas get larger, the problem cascades and the discrepancy increases.

Based on feedback from the current 2D BLE iterations in the Upper Republican custom watershed, it can be determined that the current approach to validating models to both regression equations and gage discharge estimates does not achieve desired results. Further investigation should be performed to determine whether gage records prior to 1978 should be included in gage analyses and what type of streamflow data to use to supplement the gage analyses used for flow verification in the model.

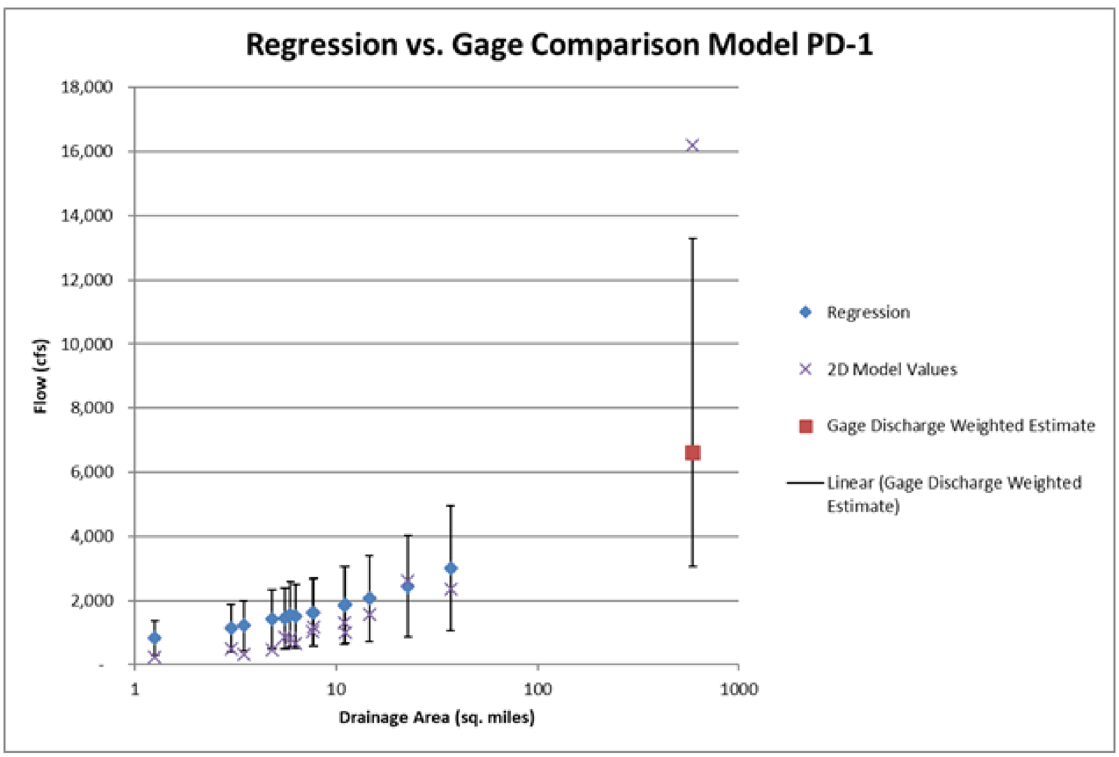

Figure 5: Hydrologic Results from 2D Model PD-1

3. AECOM Methodologies

3.1 Initial Directives

FEMA document "*Guidance for Flood Risk Analysis and Mapping: General Hydrologic Considerations*" section 7 states that the mapping partner should perform a hydrologic review the discharges in the region. "The goal of the hydrologic review is to provide an assessment of the "reasonableness" of the proposed base flood discharges and, if necessary, to suggest alternative methods that may provide more reasonable flood discharges. The reasonableness of a flood discharge depends on the study requirements and hydrologic conditions in the region of interest" (FEMA 2019). AECOM's analysis shows that the region 2 regression flows are not reasonable for this area compared to gage analyses performed on post-1978 data. Section 7.2 outlines a more specific approach for reviewing regional regression equations. "The proposed base flood discharges from the regression equations are considered reasonable if they are generally within one standard error (68-percent confidence intervals) of the gaging station estimates" (FEMA 2019). Table 2 shows that the regression discharges fall out of the 68% confidence interval range at 6 out of the 10 gage locations in the Upper Republican 2D BLE watershed.

Based on this guidance from FEMA, AECOM is providing alternatives to the current approach that may provide more reasonable discharges. AECOM tested and analyzed alternative hydrologic and hydraulic methods for modeling watersheds in Western Kansas. The following sections describe the impacts of the various approaches on the results of the 2D BLE models.

Gage ID	68% CI Lower Limit	1%-AEP	68% CI Upper Limit	Rural Regression Estimate (cfs)	Within 68% CI Range
06821500	1,798	3,375	8,681	9,987	No
06846500	1,270	2,125	4,708	11,470	No
06844900	6,641	18,810	98,980	6,903	Yes
06847900	3,218	5,763	13,200	8,147	Yes
06848000	112	123	154	8,607	No*
06847000	1,832	4,548	23,740	12,488	Yes
06827500	3,341	6,836	20,480	13,270	Yes
06846000	1,109	1,829	4,760	10,330	No
06845110	945	1,961	6,888	11,493	No
06848500	2,106	2,911	4,744	9,940	No

*Gage affected by regulation upstream

Table 2: Bulletin 17C Gage Analysis 1%-AEP Confidence Intervals

3.2 Tested Approaches

In order to develop an effective series of models that accurately reflect flooding conditions in the region being investigated, multiple methodologies were developed and tested to determine which would produce the most beneficial results. The various approaches for calibration are outlined below. The final recommended procedure draws from insights found while testing and comparing results from the different approaches. Mapped floodplain results for each approach are located in Appendix A.

Approach 1

This approach reflects the current approach outlined in section 2.3. However, only the gage analyses performed on streamflow data after 1978 were used in model verification since it was not possible to use the regression equations to supplement the flow verification in the model due to the discrepancies mentioned above. This approach was tested to assess the impacts on results in un-gaged basins and small drainage areas if the model hydrology were solely focused on flow verification at gage locations using the post-irrigation gage analysis methodology suggested in the USGS report.

As expected, this approach produces extremely low peak flows in all drainage areas of the model. The excess precipitation input had to be drastically reduced to meet the post-1978 gage estimate at the downstream outlet of the model. All flows in the model were well below the lower confidence interval of the regression estimates. Figure 6 shows the modeled flows compared to regression estimates and the modeled flow at the gage location. AECOM believes using only the gage record after 1978 underestimates the flood risk at the gage locations. Likewise, not including supplemental flow verification in upstream portions of the watershed significantly underestimates flood risk in small and medium sized drainage areas due to localized, high-intensity precipitation events.

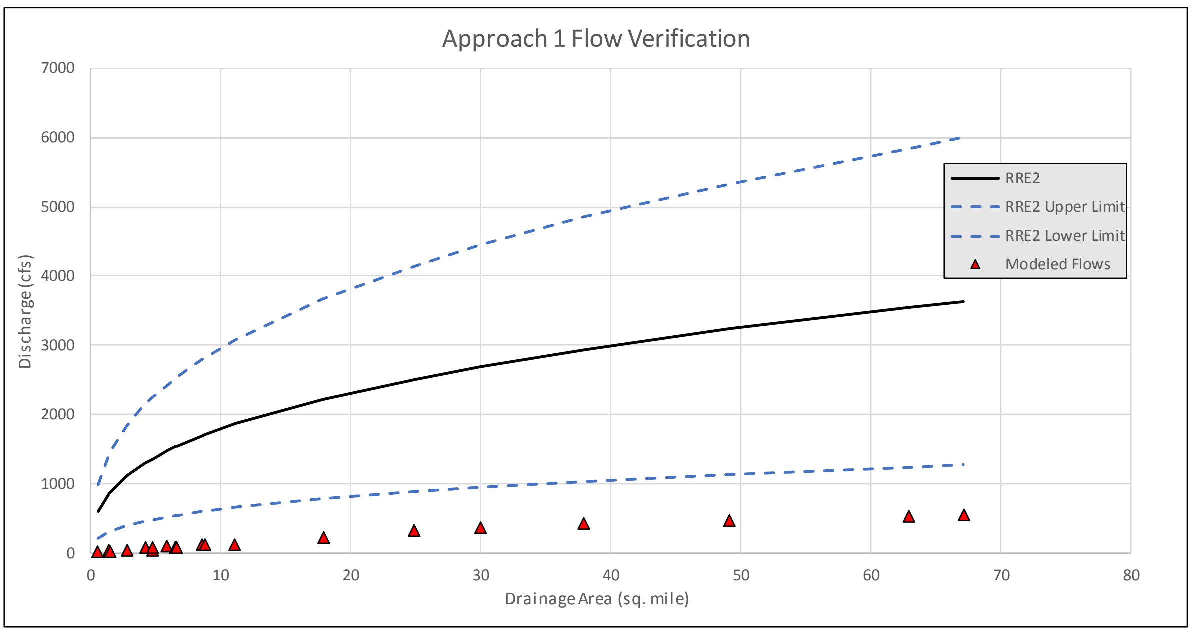

Figure 6: Approach 1 Flow Verification Results

		Post-1978 Gage Analysis				
Gage ID	Drainage Area (mi^2)	1%- AEP (cfs)	1% AEP (cfs)	1%+ AEP (cfs)	Regression Estimate (cfs)	Modeled Flow (cfs)
06846000	1,117	1,690	3,400	7,520	10,330	4,075

Table 3: Approach 1 Gage Discharge Comparison

Approach 2

In this approach, gage analyses were left out while focus was brought onto the Region II regression equation analysis in drainage areas less than 10 square miles. This approach was analyzed to assess the impacts on larger flooding sources if the model calibration was focused solely on representing the flood risk from high-intensity precipitation events in small drainage areas. While attempting to calibrate, it became apparent that the excess precipitation intensity and amounts required to meet the regression estimates in small drainage areas caused flows in downstream areas to be much higher than gage estimates and well above the upper confidence interval of the regression estimates. Hydraulic model adjustments similar to those outlined in Section 5 were made in attempt to lower the flows in larger drainage areas while maintain flows near the regression estimates in small drainage areas, but it was still not feasible in the model to accomplish both for the Beaver Creek watershed. Figure 7 shows the flow verification results from the model using this hydrology method.

In addition to that shortcoming, FEMA recommends gages to be used in calibrating particular watersheds when they are available and this approach invalidates the flow verification at the gage location in the model. Another consideration that led to the dismissal of this approach was that the regression equations for region II were developed from a small dataset and do not include data from before 1978, which has the potential to be crucial for the development of accurate flood risk in 2D BLE Models.

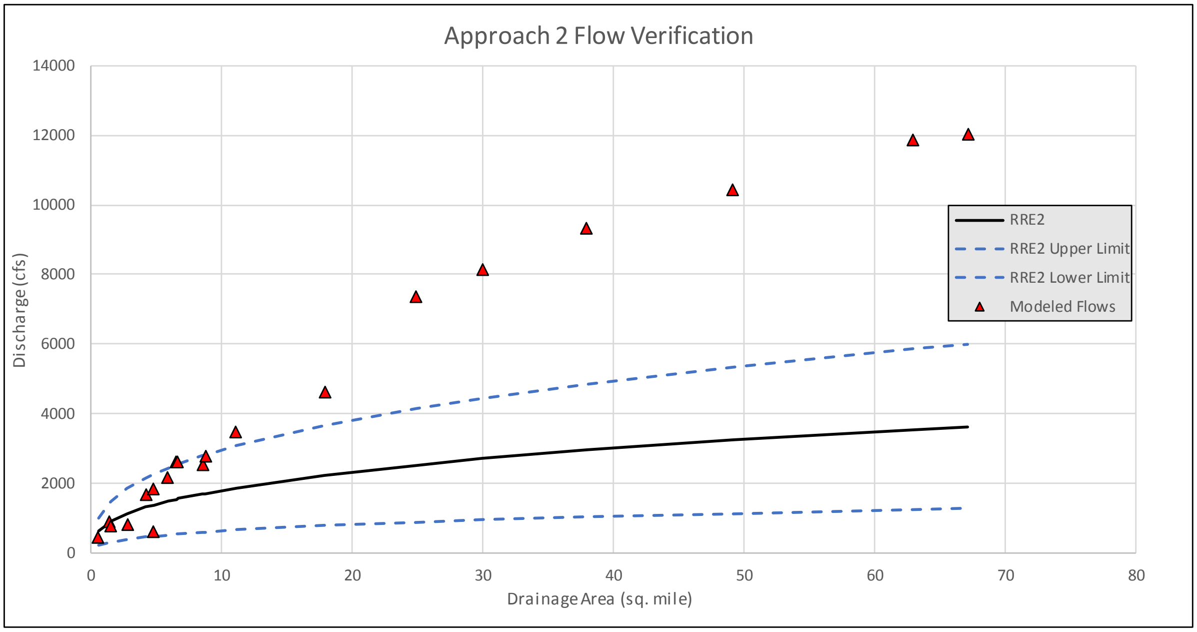

Figure 7: Approach 2 Flow Verification Results

		Post-1978 Gage Analysis				
Gage ID	**Drainage Area (mi^2)**	**1%- AEP (cfs)**	**1% AEP (cfs)**	**1%+ AEP (cfs)**	**Regression Estimate (cfs)**	**Modeled Flow (cfs)**
06846000	1,117	1,690	3,400	7,520	10,330	**30,320**

Table 4: Approach 2 Gage Discharge Comparison

Approach 3

The third approach looks to factor in gage data prior to 1978 in the gage analyses and hydrology estimates used for flow verification. A standard Bulletin 17C gage analysis performed on these gages would discard many of the low flows due from the flood frequency estimate since they do not meet the threshold determined by the Multiple Grubbs-Beck low-outlier test. Discarding the low flows experienced in recent years would not reflect irrigation effects on streamflow causing the flood frequency calculations to over-estimate the flood risk. In order to accurately account for flow data prior to 1978 and low flows experienced in recent years in the gage analyses, a mixed population gage analysis was performed. This methodology utilizes the bulletin 17C methodology to create a continuous probability distribution for the full period of the gage record. It then calculates the discrete probability of experiencing a peak flow below the low outlier threshold in a given year. The mixed population analysis then weighs the two probabilities to determine a new flood frequency estimate that factors in flows from both pre- and post-irrigation time periods.

The current USGS approach to performing gage analysis of only the post-irrigation flows caused the region 2 regression estimates at 5 out of 9 gage locations to fall outside of a 1 standard error interval of the gage flood frequency estimate as displayed in Table 2. This discrepancy renders the regression estimates unreasonable per FEMA guidance. After performing the mixed population gage analysis on all of the Upper Republican gages, only 2 gages still did not meet the FEMA standards for regression equation reasonability. In general, gage estimates were higher across the Upper Republican watershed. Gages with longer periods of record prior to 1978 tend to increase by larger amounts due to the incorporation of more pre-irrigation flows in the statistical analyses. Two of the gage flood frequency estimates actually increased above the region 2 regression estimates and fell more in line with region 1 regression estimates. Using the mixed population gage analyses makes flow verification to both gage analyses and regression estimates now feasible in basins upstream of gages that have regression estimates within the standard of error. However, USGS gage 06846000 used in the pilot study area along Beaver Creek is still further than 1 standard error from the region 2 regression estimates. Table 5 and Figure 8 show the mixed population gage analyses for the full period of record compared to regression estimates for region 1 and region 2.

Table 5: Mixed Population Gage Analyses

Gage ID	Years of Record	68% CI Lower Limit	1%-AEP	68% CI Upper Limit	Region 1 Regression Estimate (cfs)	Region 2 Regression Estimate (cfs)	Within 68% CI Range
06821500	87	23,760	34,700	54,760	24,330	9,987	RRE1
06846500	68	3,720	6,197	15,580	22,840	11,470	RRE2
06844900	50	4,364	6,407	11,150	13,540	6,903	RRE2
06847900	54	4,507	6,106	8,986	17,180	8,147	RRE2
06848000	14	112	123	154	32,350	8,607	No*
06847000	16	2,698	5,829	20,340	27,000	12,490	RRE2
06827500	116	20,210	30,580	60,690	32,350	13,270	RRE1
06846000[1]	52	3,913	5,171	7,397	23,260	10,330	No
06845110	22	945	1,961	6,888	26,760	11,490	No
06848500	89	7,905	11,680	21,670	24,330	9,940	RRE2

[1] Gage Located in Pilot Project study area

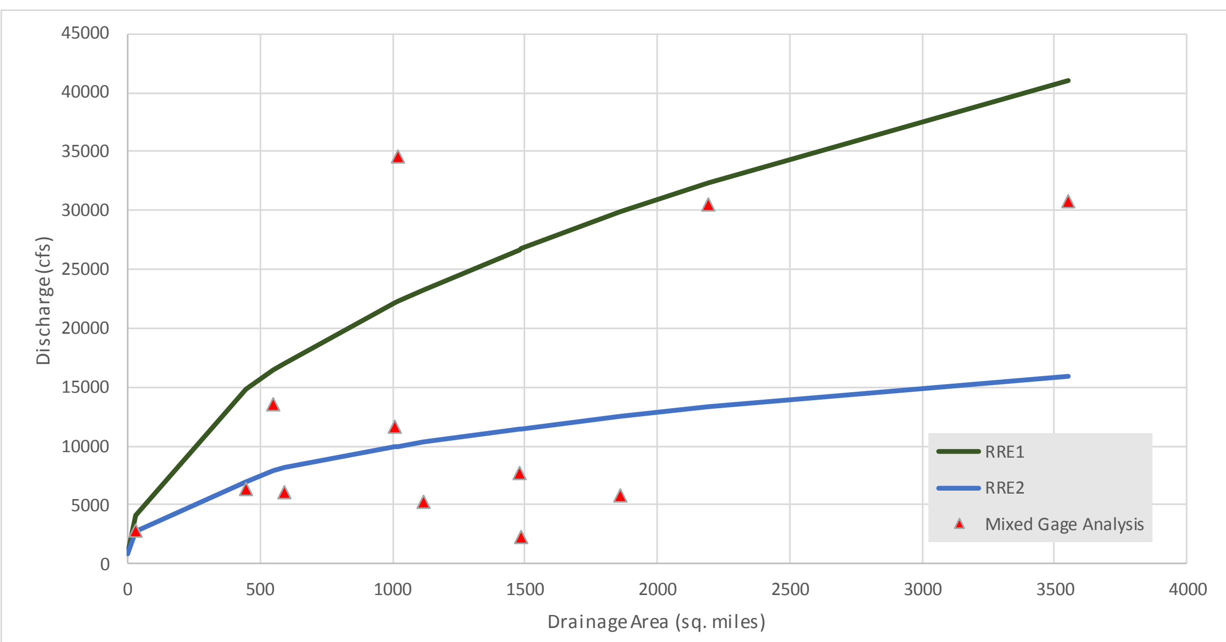

Figure 8: Mixed Population Gage Analyses vs. Regression

Results from the pilot study area for approach 3 reflect the best attempt to verify flows at all drainage areas in the model within a standard of error to region 2 regression estimates. Since the gage estimate downstream of the pilot study area is still much lower than regression estimates, the modeled flow at the gage location was not able to fall within the confidence interval of the mixed population gage at that site. The purpose of the results from approach 3 is to demonstrate that it is still feasible to use the current 2D BLE flow verification methods in basins where the mixed gage analysis and regression estimates are aligned. After the mixed population gage analysis, AECOM estimates that 3 out of the 4 HUC-8 basins within the Upper Republican custom watershed could utilize the standard flow verification method of comparing model results to both gage and regression estimates. This still leaves about 25% of the study area in need of additional adjustments to properly verify flows, including the models studied for the pilot project. Figure 9 and Table 6 shows the flow verification results of Approach 3 with nearly all flow comparisons within the standard of error provided by region 2, but still showing insufficient comparison to the gage analysis.

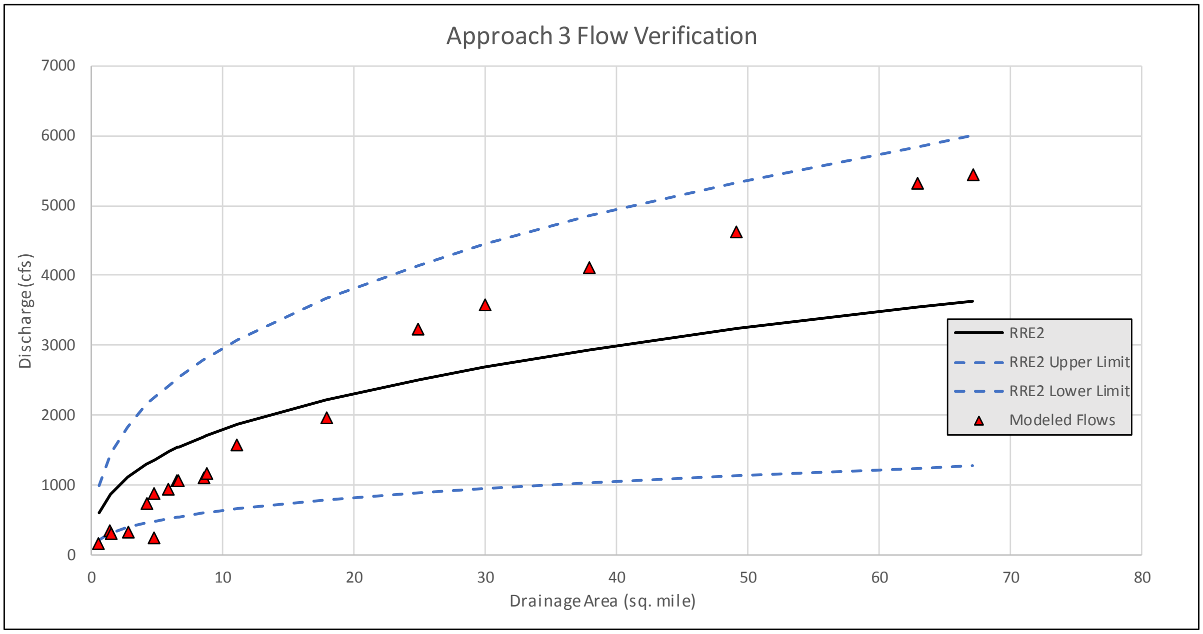

Figure 9: Approach 3 Flow Verification Results

		Full Record Mixed Population Gage Analysis				
Gage ID	**Drainage Area (mi^2)**	**1%- AEP (cfs)**	**1% AEP (cfs)**	**1%+ AEP (cfs)**	**Regression Estimate (cfs)**	**Modeled Flow (cfs)**
06846000	1,117	3,910	5,170	7,400	10,330	**15,200**

Table 6: Approach 3 Gage Discharge Comparison

Approach 4

As determined in approach 3, the gage analysis and regression estimates in the pilot study area were still not aligned after performing the mixed population gage analysis. The flow verification issues outlined in section 2.3 are still present while modeling this area. Approach 4 uses a smaller work area size around an area of interest in attempt to allow for flow verification to a localized area. In this case, a 66 square mile model area centered on Atwood, KS was extracted from the larger BVR-1 model. Figure 10 displays the new model area boundary used for this approach.

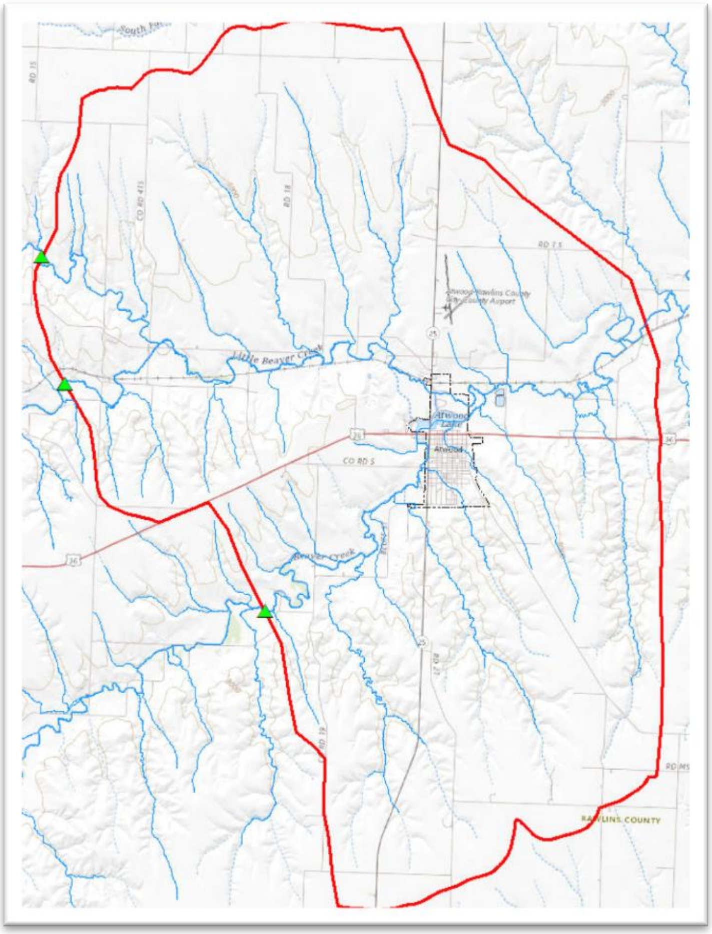

Figure 10: Atwood Model Study Area

Creating a localized model area allows for the excess precipitation input to be increased without over-estimating the flows in larger, gaged flooding sources. A long duration, high volume event can be represented by controlling the inflow hydrographs to the model from upstream drainage basins. A localized, high-intensity event can be represented by controlling the excess precipitation input. The timing of the peak excess precipitation and the peak inflow hydrographs can be manipulated to effectively model two types of storms in the same model. The results from this approach demonstrate the modeled flows are able to fall within the standard of error of the mixed population gage analysis along Beaver creek while also producing flows in the tributaries that are within the standard of error of regression estimates. These results were not achievable in previous approaches that were tested. Figure 11 and Table 7 display the flow verification results from the localized Atwood model.

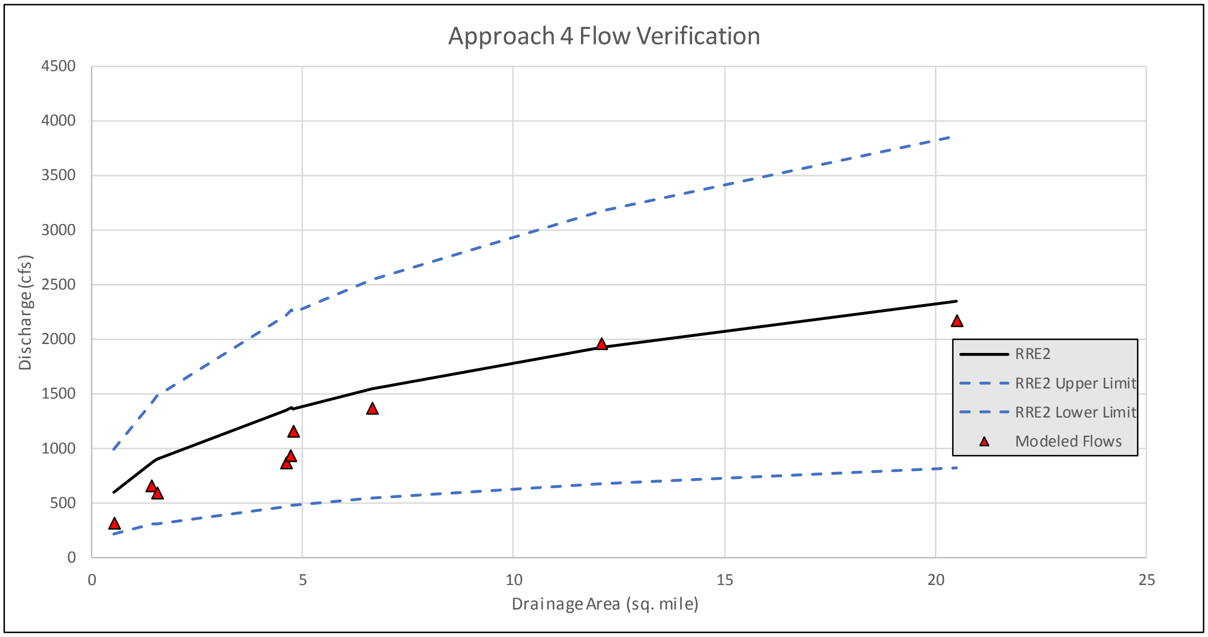

Figure 11: Approach 4 Flow Verification Results

		Full Record Mixed Population Gage Analysis				
Gage ID	Drainage Area (mi^2)	1%- AEP (cfs)	1% AEP (cfs)	1%+ AEP (cfs)	Regression Estimate (cfs)	Modeled Flow (cfs)
06846000	1,117	3,910	5,170	7,400	10,330	**5,150**

Table 7: Approach 4 Gage Discharge Comparison

The results from this approach demonstrate it is possible to verify flows in accordance to Zone A FEMA standards by creating localized 2D model to an area of interest. The magnitude of the discrepancy between the gage estimate and the regression equations can determine how large or small of an area a model boundary would need to be to satisfy the flow verification results. This approach can be utilized in basins with similar characteristics to the Beaver Creek watershed where irrigation impacts result in gage estimates and regression estimates to differ significantly.

4. Recommended Procedures

Based on the results of the hydrologic and hydraulic methods tested during the pilot study, AECOM has developed a recommended procedure to apply in Western Kansas on a custom 2D BLE watershed study area scale. The procedure draws insights from the different flow verification approaches and previous 2D BLE studies. It is recommended that the final hydrologic and hydraulic methods used are determined on a case-by-case basis for individual basins within a 2D BLE study area. The fundamental assumptions used to develop the approach are listed in Table 8.

Assumptions	Reasoning
Gage analyses serve as the highest priority for verifying peak flows in a hydraulic model	FEMA standards suggest stream gage data should be used to estimate flood discharge-frequency relations on streams with sufficient stream gaging station data.
Gage analysis should include peak flow record prior to 1978	Historical flood data should be included in discharge estimates to not under estimate potential flood risk. Longer period of record provides more confidence in statistical

	analysis.
Mixed Population gage analysis should be used in areas affected by irrigation	Mixed population analysis is the best way to estimate flood frequency while factoring in probabilities of both pre- and post-irrigation effected flows.
Certain basins are affected by irrigation more than others	Figure 3 demonstrates that irrigation effects are concentrated in certain areas within Kansas. The effects on streamflow should not be assumed to be uniform across the western half of the state.
Regression Estimates are considered reasonable if they are within the standard error of gage analyses	FEMA guidance suggests regression estimates are considered reasonable if they are within 1 standard of error from gage analysis results. If flows are not reasonable, alternative methods should be explored or explanations provided to why they are different.

Table 8: Fundamental Assumptions

The first step when beginning a 2D BLE study area in Western Kansas should identify the gages with sufficient record in the area to use for hydrologic analysis. Mixed population gage analysis in accordance with Bulletin 17C should be performed on all applicable gages in the study area to determine the 68% confidence interval for the 1% annual exceedance probability event. Regression estimates using Region 1 and Region 2 equations are then determined at all stream gage locations. A comparison of the gage estimates and both regression estimates should then be performed similar to Table 5 in Section 3.2.

Based on this comparison, AECOM has identified three potential cases in which individual basins within a study area can be categorized. The three categories of basins will most likely require different flow verification methodologies to accurately model the watershed areas upstream and downstream of a given stream gage. The necessity for using varying flow verification methods arises from differences in period of record in stream gages and differing irrigation impacts from basin to basin. The three potential basin categories are described in Table 9.

Case	Description
1	Basins with Region 1 rural regression estimates that are in accordance with mixed population gage discharge estimates.
2	Basins with Region 2 rural regression estimates that are in accordance with mixed population gage discharge estimates.
3	Basins with Region 1 or Region 2 rural regression estimates that are not in accordance with mixed population gage discharge estimates.

Table 9: Basin Categories

4.1 Case 1 Flow Verification Method

Basins that fall into this category should utilize the mixed population gage discharge estimates as the first priority of flow verification and region 1 regression estimates as supplemental flow verification in ungaged locations. Basins in this category may be encountered due to extended period of record at gage locations within the basin, or the stream loss due to irrigation effects is not as prominent compared to other areas of Western Kansas. Although region 2 regression estimates are meant to be used in Western Kansas, the region 2 regression estimates may be considered unreasonable per FEMA standards. If the region 1 regression estimates fall within one standard error of gage analyses, AECOM considers this set of equations to be more reasonable for supplemental flow verification. An example of a case 1 basin in the Upper Republican study area would be the South Fork Republican HUC-8 basin, with USGS gages 06821500 and 06827500 flood frequency estimates above region 1 regression estimates. This is likely due to the extended period of record of 87 and 116 years at the two gages. In this basin, it is more feasible to meet flow verification targets in upstream portions of the 2D models using region 1 estimates due to the increased flow verification target downstream at gage locations.

The established 2D BLE methodologies applied in previous studies in other areas of the state should be sufficient to verify flows in the models using region 1 equations as the primary supplement in these basins. A potential downside to this case would be floodplains that are wider than floods experienced recently. This could cause some members of the communities to assume the study is over estimating the flood risk in the area.

4.2 Case 2 Flow Verification

Basins that fall into this category should utilize the mixed population gage discharge estimates as the first priority of flow verification and region 2 gage discharge estimates as supplemental flow verification in ungaged locations. AECOM estimates this type of basin to be most frequently encountered in western Kansas since 5 out of 9 gages within the Upper Republican watershed fell in to this category. Results from Approach 3 demonstrate it is possible to properly verify flows within a standard of error of regression estimates and within the standard of error of gage analyses. Pilot study testing showed model calibration may require flows to be toward the lower bound of the confidence interval in drainage areas below 10 square miles and toward the upper bound of the confidence interval in drainage areas above 40 square miles. However, multiple flow verifications within the standard of error should be sufficient for BLE model results. The established 2D BLE methodologies applied in previous studies in other areas of the state should be sufficient to verify flows in the models using region 2 equations as the primary supplement in these basins. AECOM expects results in these basins to be most realistic when viewed from the community stand point considering recent flooding events.

4.3 Case 3 Flow Verification

The pilot study basin of Beaver Creek would fall into this category of flow verification. Hopefully this case is encountered less frequently in 2D BLE study areas. As determined by the pilot study results, none of the approaches using current model sizes were capable of verifying flows to both gage and regression estimates. Helpful hydrologic and hydraulic model adjustments outlined in Section 5 can be used to attempt to maintain higher flows in smaller drainage areas while not increasing the flow at gage locations downstream beyond the upper limits of the confidence interval; however, these adjustments may not suffice in satisfying flow verification targets throughout the entire watershed. It is recommended to use smaller model area sizes in such basins. A possible downside to smaller basin sizes is difficulty in monitoring water surface elevation tie-ins at model transition locations. Models similar to approach 3 for the Atwood area may be sufficient in providing BLE data, but do not meet Zone A standards. In this case, AECOM recommends creating localized hydraulic models from the BLE models for areas of interest to allow the hydrologic inputs to be focused on a specific area before moving to Zone A regulatory floodplains. This method can allow for proper flood risk due to flash flooding and in large flooding sources impacted by irrigation to be communicated in the mapped results.

5. Helpful Model Adjustments

While performing 2D hydraulic analyses on study areas in western Kansas, it is expected there may be situations encountered where it is challenging to meet flow verification targets in small and large drainage areas within the same model. In basins with characteristics similar to Case 2 or Case 3, the challenge becomes maintaining high enough peak flows in small drainage areas to represent flash flooding events without significantly over-estimating flows at downstream gage locations. Hydrologic and hydraulic model adjustments can me made in attempt to properly calibrate the hydraulic model to flow verification targets, but may not completely suffice in meeting Zone A hydrologic standards in some situations. The end result of the BLE models is a water surface elevation spatial dataset, so some adjustments may require atypical ways to achieve desired Water Surface Elevation results throughout the watershed. Standard 2D BLE methodologies should be applied where possible, and any model adjustments beyond the standard BLE approach should be documented and reassessed for reasonability before moving to Zone A products. AECOM provides some hydrologic and hydraulic concepts learned from the pilot project that may be helpful in basin situations similar to case 3.

Hydrologic Input Timing

One of the most impactful ways to control peak flows along larger flooding sources is to adjust the timing of the peak excess precipitation with respect to the peak inflow from upstream models or watersheds. The timing of the precipitation event does not impact flows in smaller drainage areas affected only by rain-on-grid precipitation, but the difference in peak times does largely impact flows in larger flooding sources with inflow hydrograph inputs to the 2D model. If the peak of the inflow hydrograph and the excess precipitation are coincident, flows downstream will be increased significantly due to the flooding events occurring at the same time. Spacing out the peak timing allows the flooding from the excess precipitation event and the inflow hydrograph to be largely independent events. This effectively creates the ability to model two types of storms in the same model. The two types being flash flooding and longer duration, higher volume storms that impact larger flooding sources. The model is able to better control the peak flows downstream with the inflow hydrograph input. Results from Approach 4 testing, show the significant difference in flows at the gage locations by solely adjusting the hydrologic input timing. All flow verification locations impacted only by excess precipitation did not change by greater than .01%. Figure 12 shows the peak discharge at the downstream gage location was able to be reduced by 40% or 3,400cfs by using multiple peaks. This allows the resulting water surface elevation outputs to reflect both the high peak flows caused by the excess precipitation, while reflecting reduced streamflow results aligned with gage analyses in larger flooding sources. In future iterations of HEC-RAS software, it may also be possible to adjust timing and magnitude of excess precipitation hyetographs within the same model to allow for greater flexibility in managing peak discharges in the model. While this method may improve a model's flow verification results, it may cause increased simulation times and increased volume of flooding compared to observed events at gage locations; however, it does allow for better water surface and discharge results in a BLE model.

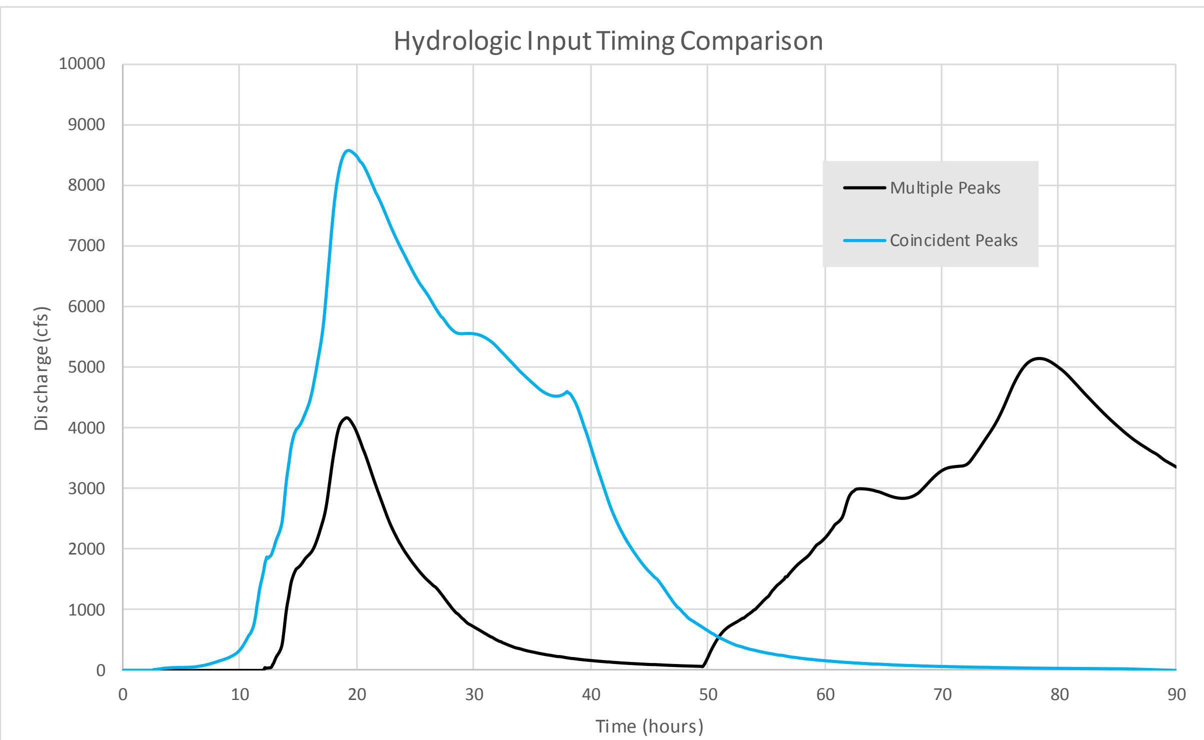

Figure 12: Hydrologic Input Timing Comparison

Decreased Model Area Sizes

Decreasing the model area sizes can be useful in basins similar to the pilot study area of Beaver Creek or other areas that utilize the region 2 regression estimates. AECOM found that high intensity precipitation distribution such as the NRCS nested hyetograph applied on too large of a model size can create flows in drainage areas to outpace regression and gage discharge estimates in drainage areas over 100 square miles. This is likely due to the flooding sources in the model areas all experiencing the peak hydrologic input at the same time. Smaller model areas can allow for greater flexibility in managing the hydrologic inputs and controlling the flows in downstream areas by utilizing the multiple peaks method as demonstrated by results from Approach 4.

Smaller model areas may cause some loss of efficiency when attempting to model custom watersheds comparable in size to the Upper Republican 2D BLE study due to the increased amount of hydraulic models necessary cover the entire area. This method may also present additional challenges at model tie-in locations to create seamless water surface elevation results from model to model. Spatially varied precipitation inputs in future HEC-RAS versions may also provide additional tools to address this problem in future BLE studies.

Manning's N Override Regions

HEC-RAS 5.0.7 allows for modelers to create manning's n override regions for specific areas in the 2D model. This feature can be used to increase the manning's n roughness values in the channel and overbanks or large flooding sources where necessary. In basins similar to the Beaver Creek, it may be necessary to increase the manning's n values above realistic estimates for deep, channelized flooding to lessen peak flows in large drainage areas.

Various tests performed during the hydrology pilot study used a manning's n value of 0.20 for the channel and overbanks of any flooding source with over 20 square miles in drainage area. The results from testing show the peak flows in smaller drainage areas were able to remain unaffected, but the peak flows in the larger flooding source were reduced by up to 38%. Figure 13 shows the comparison of the same excess precipitation input using typical manning's n values compared to using an increase Manning's n value override region.

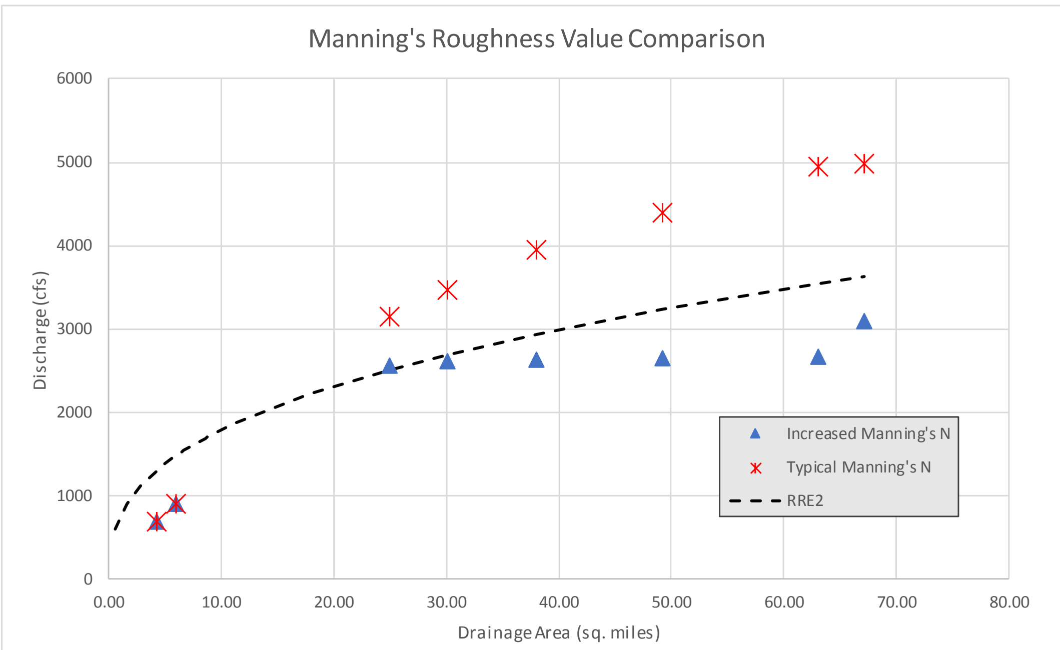

Figure 13: Manning's N Override Comparison

This hydraulic adjustment should only be used where necessary in BLE models to achieve desired discharge and water surface elevation results. Increasing the manning's n value above reasonable limits would not allow the model to meet Zone A standards. This could cause unreasonable volumes of flow to be routed through the model and affect output velocity results. If this hydraulic adjustment is necessary, it should be documented and re-evaluated before using the results for Zone A products.

6. References

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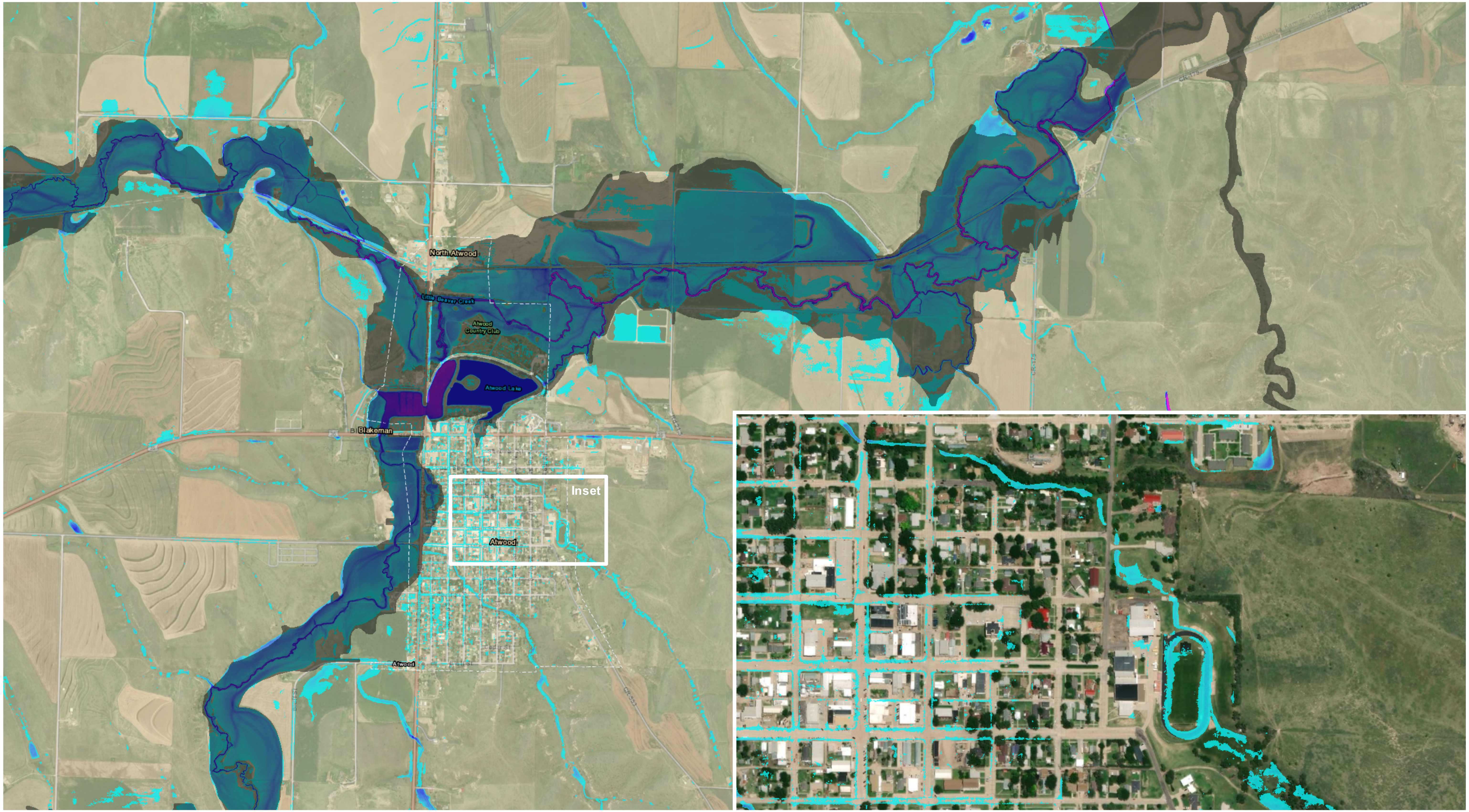
Painter, C.C., Heimann, D.C., and Lanning-Rush, J.L., 2017, Methods for estimating annual exceedance-probability streamflows for streams in Kansas based on data through water year 2015 (ver. 1.1, September 2017): U.S. Geological Survey Scientific Investigations Report 2017–5063, 20 p.,

Appendix A : Mapping Exhibits



ATWOOD, KANSAS
HYDROLOGY SCENARIO 1:
POST-1978 GAGE VERIFICATION

Scenario1_Depth

High : 26.8

Low : 0

Effective Flood Zone

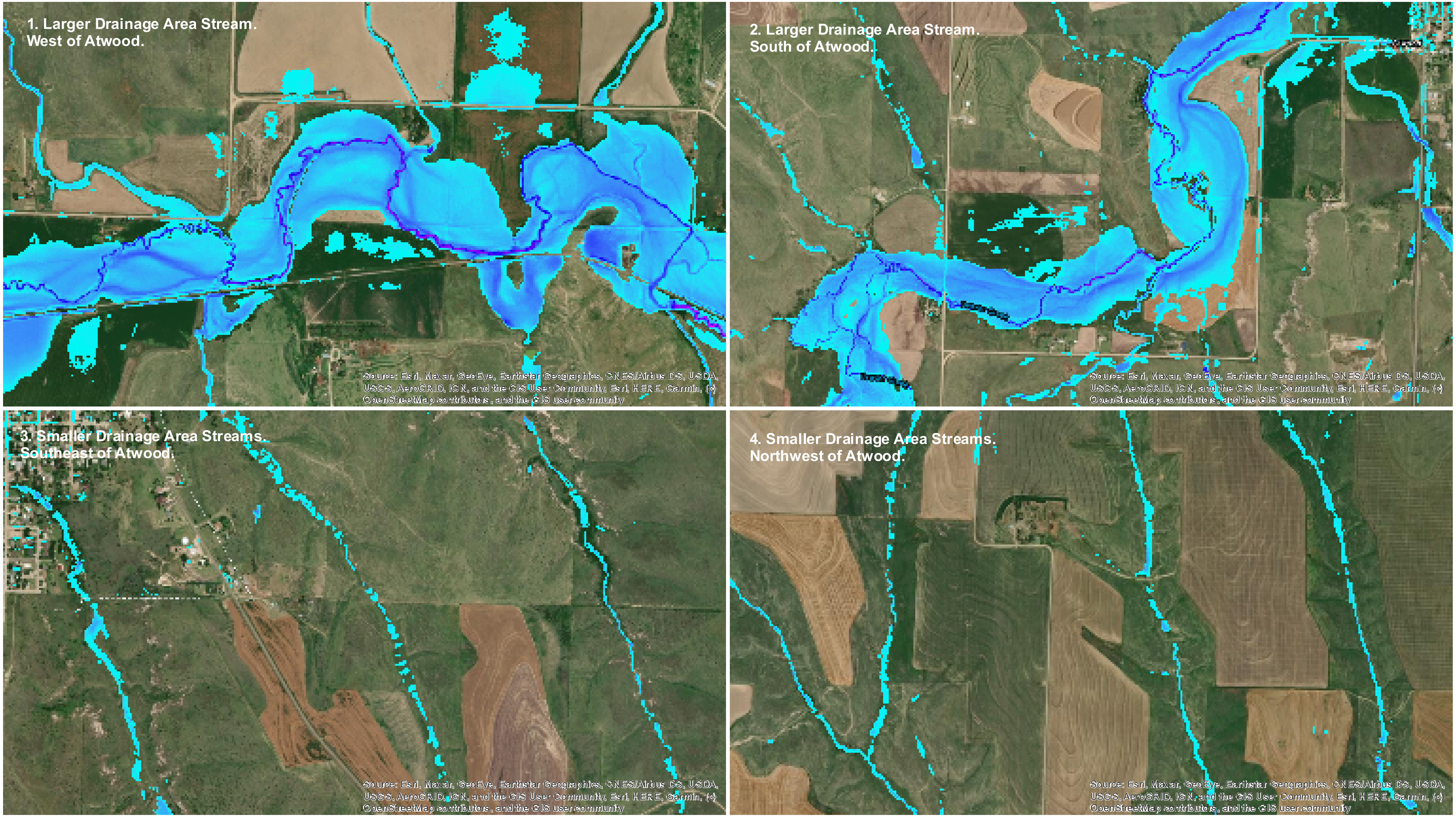
A,

AE,

December 2020

Kansas Department of Agriculture

AECOM



ATWOOD, KANSAS
HYDROLOGY SCENARIO 1:
POST-1978 GAGE VERIFICATION

Scenario1_Depth

Value

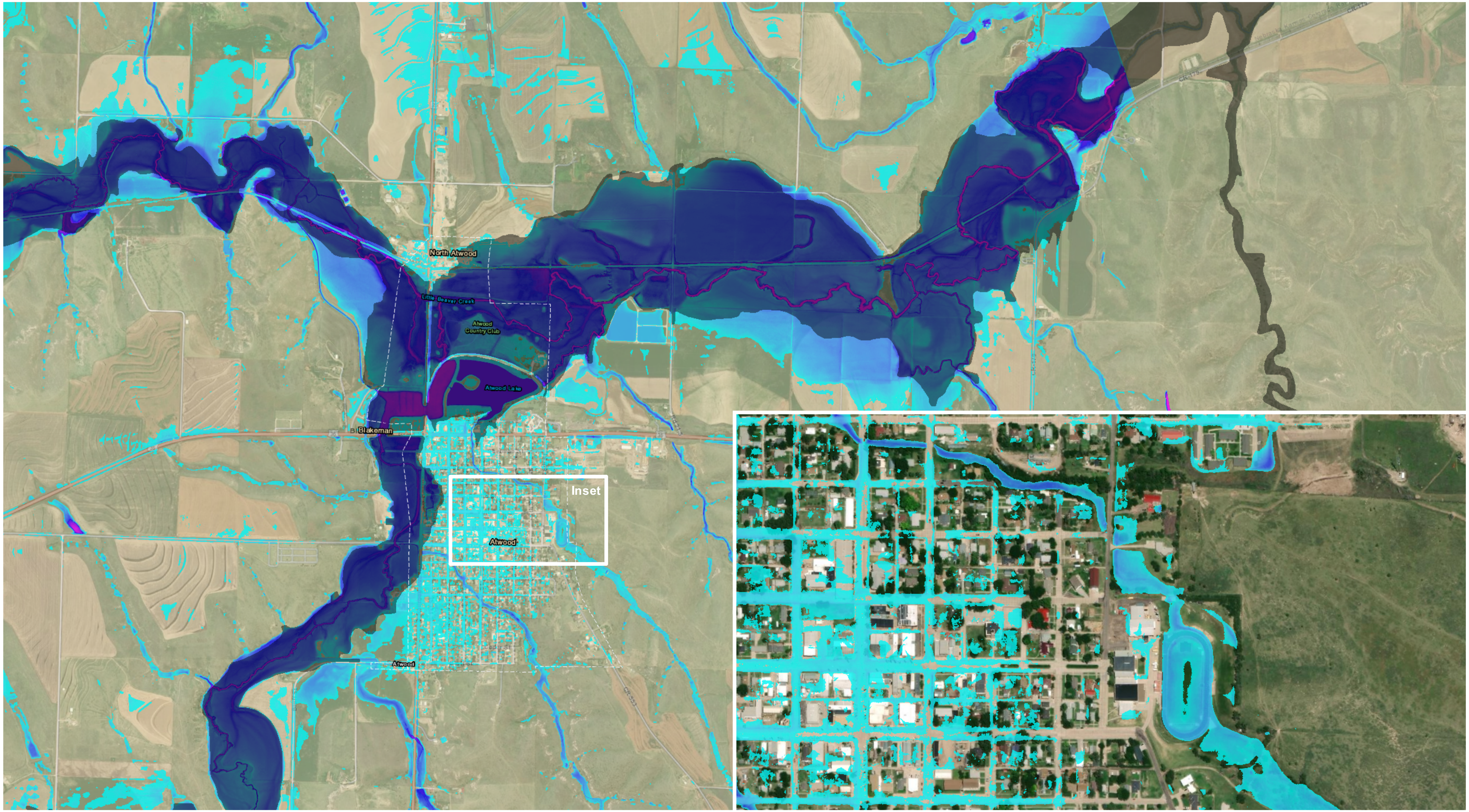
High : 26.8

Low : 0

December 2020

Kansas Department of Agriculture

AECOM



ATWOOD, KANSAS
HYDROLOGY SCENARIO 2: REGRESSION WEIGHTED SCENARIO

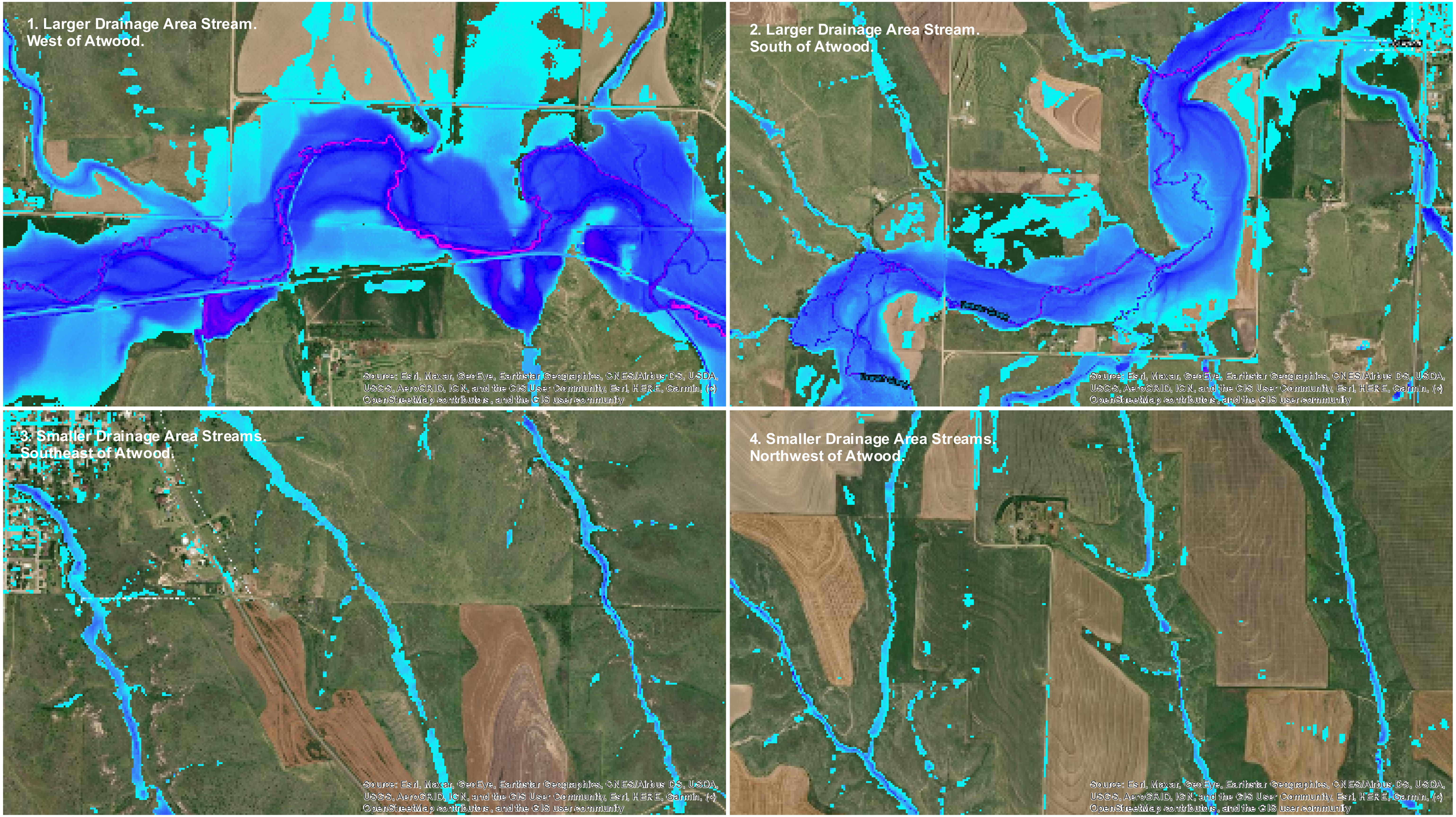
Scenario2_Depth
High : 40.9
Low : 0

Effective Flood Zone
A,
AE,

December 2020

Kansas Department of Agriculture

AECOM



ATWOOD, KANSAS
HYDROLOGY SCENARIO 2:
REGRESSION WEIGHTED SCENARIO

Scenario2_Depth

Value

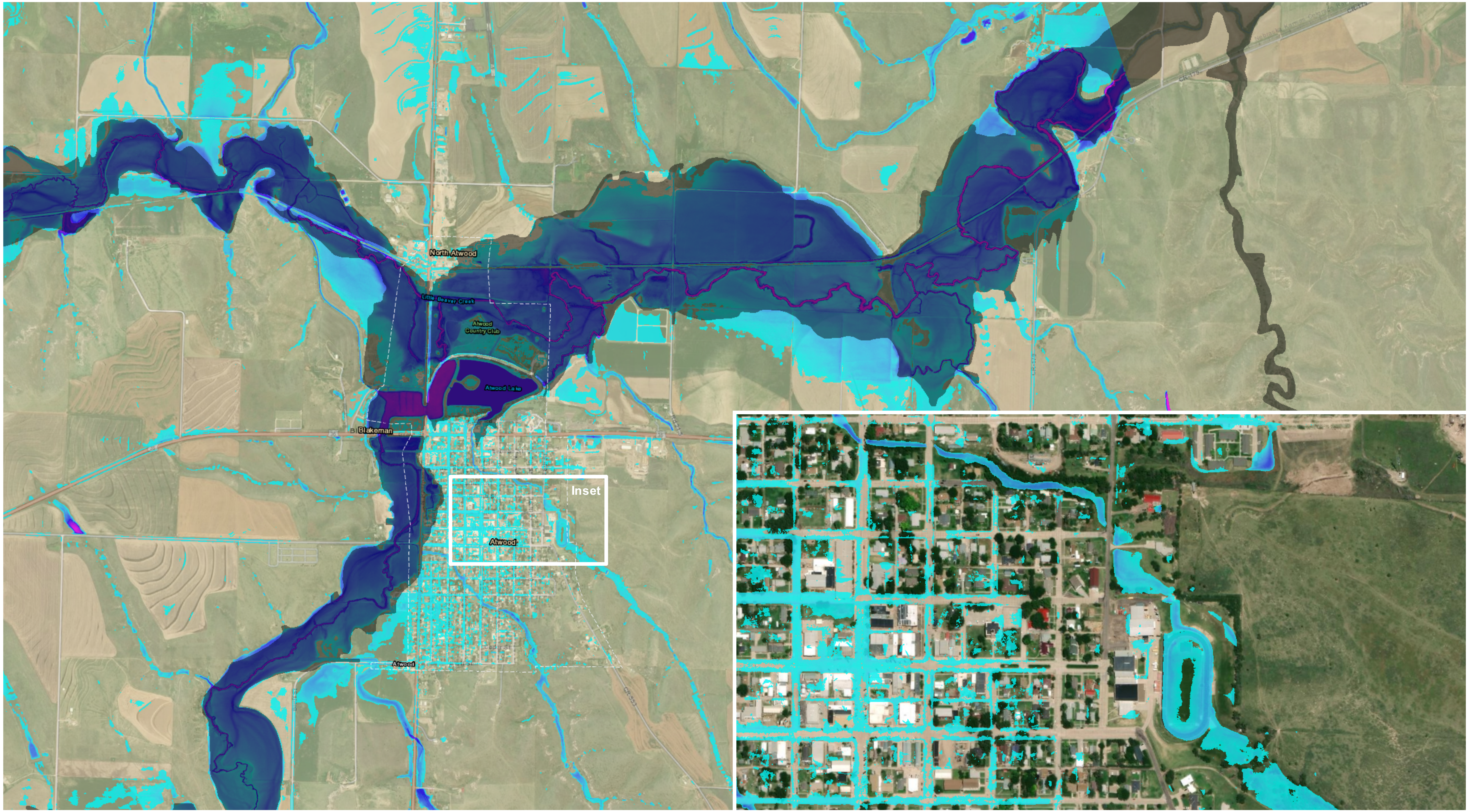
High : 40.9

Low : 0

December 2020

Kansas Department of Agriculture

AECOM



ATWOOD, KANSAS
HYDROLOGY SCENARIO 3:
FULL RECORD GAGE SCENARIO

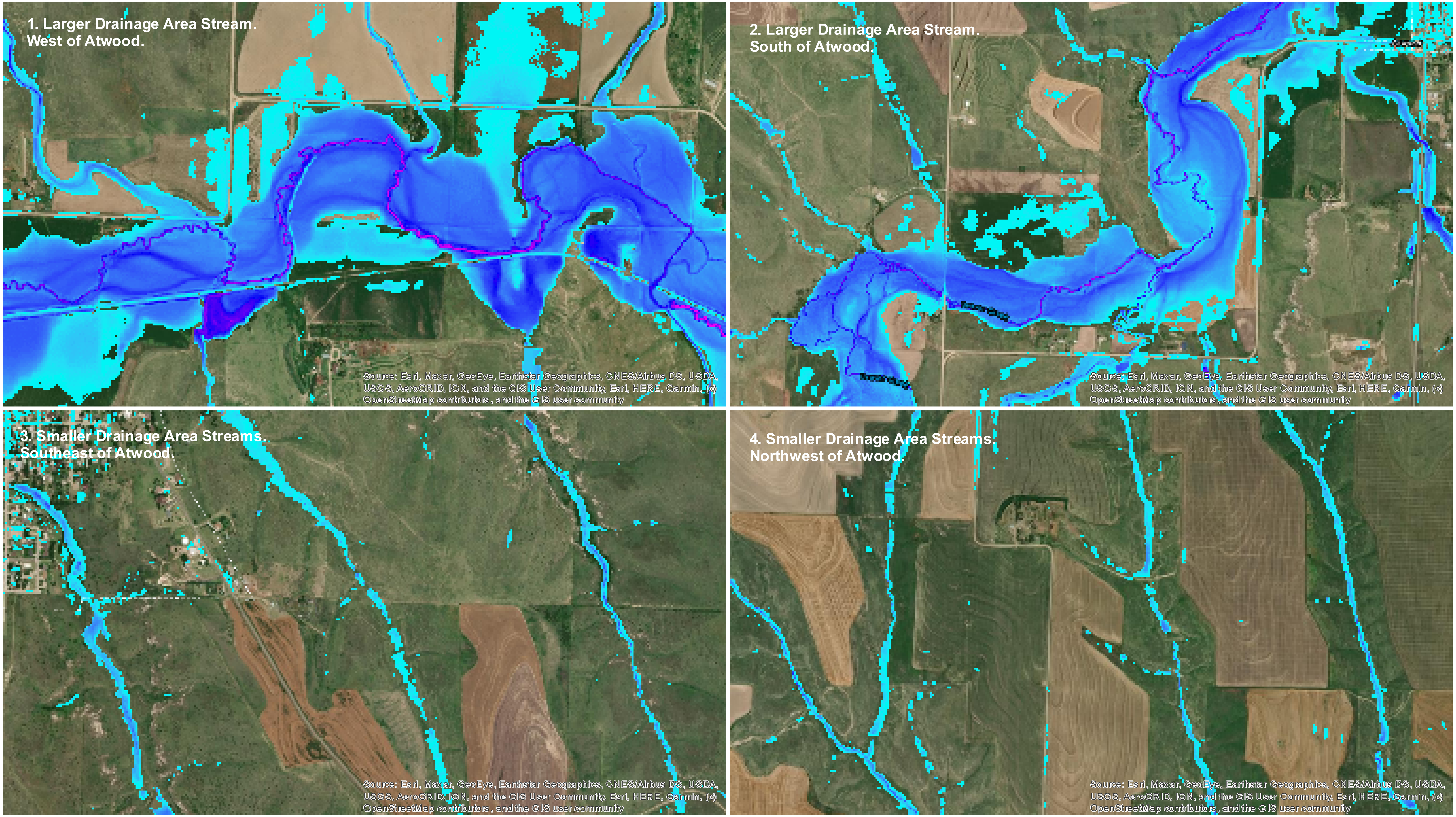
Scenario3_Depth
High : 39.8
Low : 0

Effective Flood Zone
A,
AE,

December 2020

Kansas Department of Agriculture

AECOM



ATWOOD, KANSAS
HYDROLOGY SCENARIO 3: FULL RECORD GAGE SCENARIO

Scenario3_Depth

Value

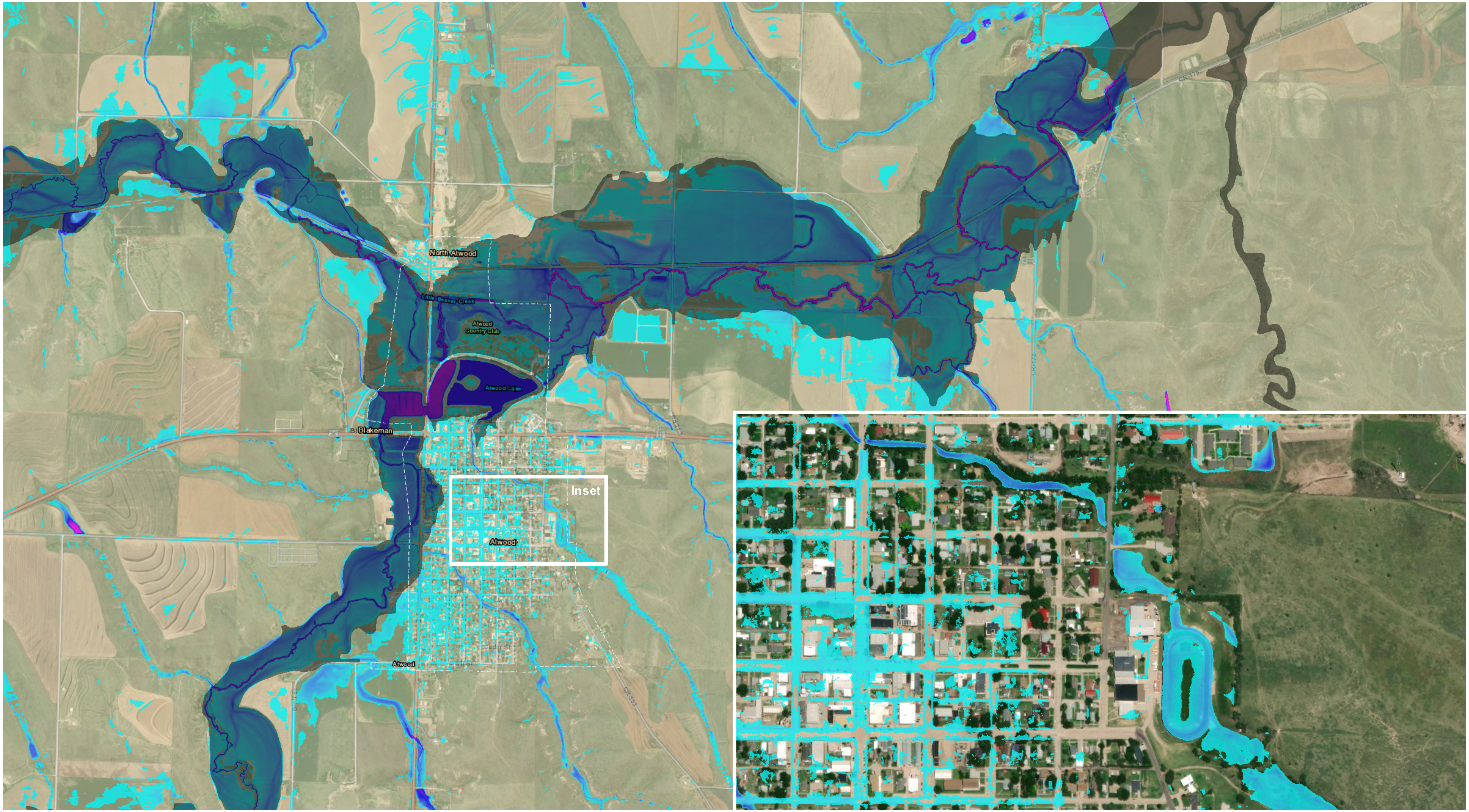
High : 39.8

Low : 0

December 2020

Kansas Department of Agriculture

AECOM



ATWOOD, KANSAS
HYDROLOGY SCENARIO 4:
LOCALIZED FLOW VERIFICATION

Scenario4_Depth

High : 39.6

Low : 0

Effective Flood Zone

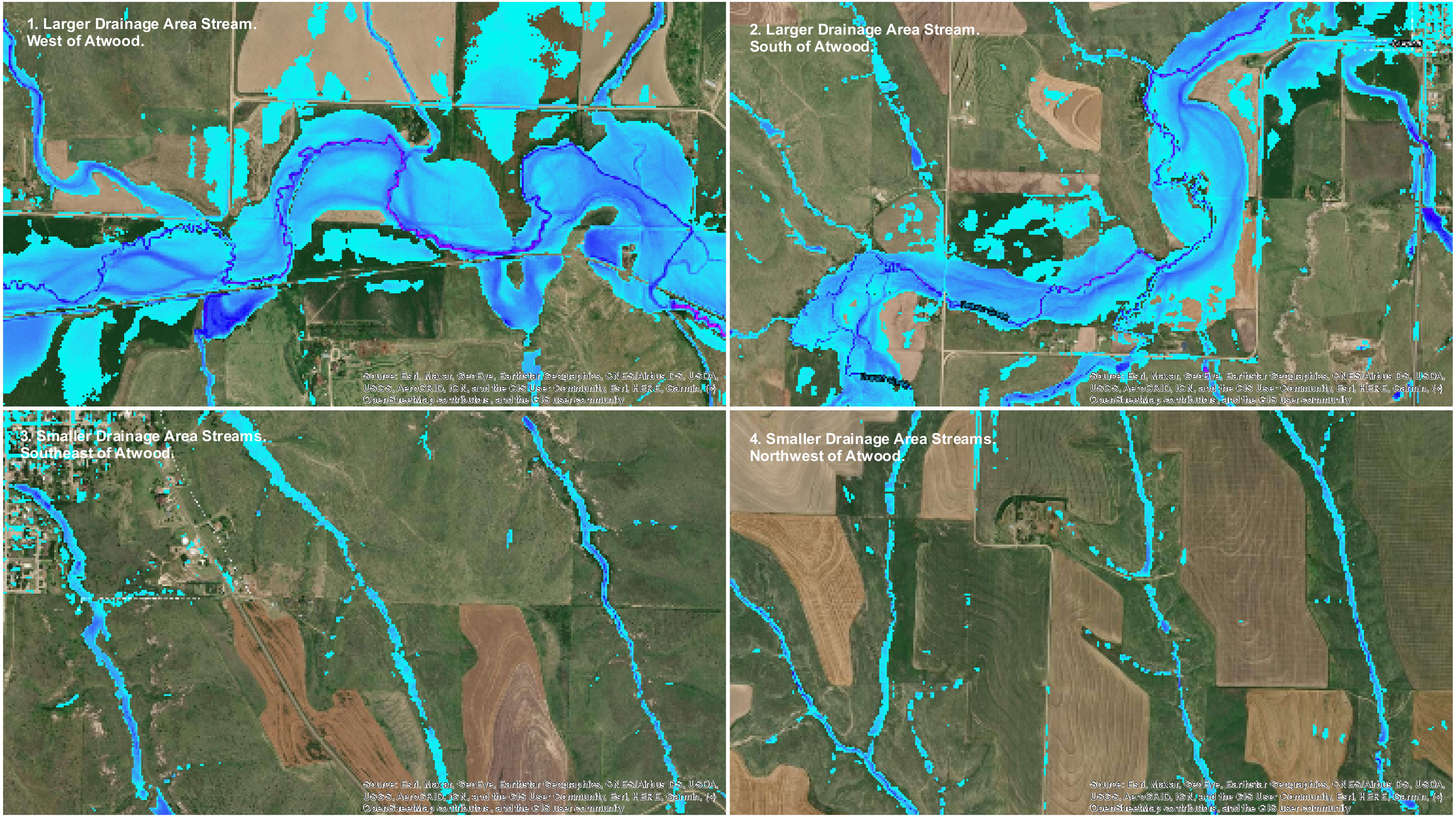
A,

AE,

December 2020

Kansas Department of Agriculture

AECOM



ATWOOD, KANSAS
HYDROLOGY SCENARIO 4:
LOCALIZED FLOW VERIFICATION

Scenario4_Depth

Value

High : 39.6

Low : 0

December 2020

Kansas Department of Agriculture

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